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Breeding Methods Used in Maintenance and Improvement of

ACALA 4-42

Variety of Cotton

Agricultural Research Service
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EXPLANATION OF TERMS

SELECTION--"an individual plant" selected by the breeder. Each year thousands of plants are chosen for self-pollination, but only 500 to 1,000 are selected for planting the following year.

PROGENY--"a group of plants" (or a row) grown from seed of one plant. Each year over 500 progenies are grown. The best 10 to 20 percent furnish seed for preliminary tests while their elite plants are used for progenies in the breeding nursery the following year.

FAMILY--"a group of progenies" derived from the same lineage. Each year the best 10 to 25 families are tested while selections from the component progenies are used in the breeding nurseries.

STRAIN--"a group of related families." Seed of related families is pooled to constitute a strain. Several such strains are tested each year and the one giving the highest yield, quality, and production efficiency becomes the official release the following year.

PROGENY INCREASE--self-pollinated seed from progenies of the best families is planted in small isolated plots. One or all families may be used the following year in the official seed release.

FOUNDATION--seed from the Progeny Increase is used to plant 250 acres. This first step in seed multiplication is grown under Seed Distributors contract.

WHITE TAG--seed from the Foundation field is used to plant 3,500 acres. Grown under Seed Distributors contracts.

PURPLE TAG--seed from WHITE TAG fields is used to plant 60,000 acres. Grown under Seed Distributors contracts.

GREEN TAG--seed from PURPLE TAG fields is available to all growers, as the "Model" of planting seed for the entire One-Variety district.

GIN RUN--seed from GREEN TAG fields that goes to oil mills for crushing.

Prepared in

Crops Research Division
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BREEDING METHODS USED IN MAINTENANCE AND IMPROVEMENT OF THE ACALA 4-42 VARIETY OF COTTON

By

John H. Turner[1]

The Acala 4-42 variety of upland cotton (Gossypium hirsutum) is grown in the One-Variety district of California. This district includes all cotton-producing counties in the San Joaquin Valley and accounts for 92 percent of California's cotton acreage.

Breeding and release of the foundation seed is the responsibility of the U.S. Cotton Field Station at Shafter. The management of seed multiplication and distributions is the function of the California Planting Cotton Seed Distributors, a nonprofit growers' organization (7)[2].

Since the formation of this Acala One-Variety district in 1926, the San Joaquin Valley farmers have depended upon the station for the varietal improvements needed to meet the changing conditions of growing and marketing the cotton crop. Although several changes in Acala strains were made, the most significant was the release of Acala 4-42 to replace Acala P18C in 1949.

Acala 4-42 originated with a plant selection made by George J. Harrison from Acala 1517 in 1939. Several progenies in the 1942 nursery, all of which traced back to plant selection number 4 in 1939, were excellent agronomic types and had fiber quality definitely superior to Acala P18C. Self-pollinated seed from these progenies formed the nucleus of the first increase (4).

Continued selection pressure within this new Acala strain by Harrison for tolerance to verticillium wilt, yield attributes, and fiber quality resulted in a number of plant and fiber types. In 1950, Harrison identified 12 sib lines having distinct phenotypic differences. These sib lines were called "families." At least 8 of these families possessed high wilt tolerance. The pedigreed records revealed that all 12 families descended from 2 individual plants (numbered 4-8 and 4-25) of 1946. Self-pollinated seed derived from only the wilt-tolerant families was used in the Foundation seed release of 1951, which reached valley-wide production in 1954 and proved to be another significant varietal improvement (10).

This breeding program has to take into account several contributing elements.

1. Cultural practices are constantly changing in a farm economy geared toward complete mechanization.

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[1] Research Agronomist, Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture. The author is grateful to his predecessor, George J. Harrison, and the following associates for the important role they have had in the breeding, genetic, and testing phases of the program--Audy Bell, G. T. Den Hartog, Bob Hines, S. C. McMichael, R. J. Miravalle, Merrill Lehman, Angus Hyer, and Noel Smith.

[2] Underscored numbers in parentheses refer to Literature Cited, p.13.

2. The plant's environment is gradually being altered by changing insect populations and disease problems, varying crop sequences, and increasing use of agricultural chemicals and irrigation water.

3. Rapid changes are being made in the gin, many of which subject the fiber to more drastic machine damage.

4. The demands from the raw product consumer are subject to continual change as the textile industry develops new spinning and processing methods.

Keeping these contributing elements in mind, the breeder endeavors to alter gradually the genotypic constitution of the variety to meet the production, processing, and marketing demands. The yearly release of foundation seed is destined to become the variety's "model" of planting seed for all valley growers 3 years later (fig. 1). Therefore, the technical decision the breeder must make as to what seed to release is of large economic consequence. Using the most effective breeding methods known and guided by reliable testing procedures, the breeder attempts to manage the genetic variability existing in his breeding stocks to best advantage.

STAGES OF VARIETAL DEVELOPMENT

The main purpose of this paper is to describe the breeding methods and techniques used in the maintenance and improvement of the Acala 4-42 variety. This varietal improvement program can best be described by presenting separately the three stages of development that occur annually and by defining terms that are somewhat unique to the California program.

Stage 1 - Breeding Nursery

A pure line, pedigreed selection system is followed in the breeding nursery. Each year several hundred progeny rows are planted with self-pollinated seed from individual plants selected the previous year. This nursery is located on a plot of land that is heavily infected with the verticillium wilt organism (*Verticillium albo-atrum* Reinke & Berth), which is the most damaging disease in the valley. To gain and maintain a high level of wilt tolerance the breeder plants the more important progenies on this plot every year.

In 1953, when the writer became head of this program, 10 families of Acala 4-42 were represented in the nursery (4 to 8 progenies from each family). Apparently considerable variability existed among these families. Harrison and the writer evaluated plant selections in each family for over 20 agronomic traits during the 1953 growing season. Samples from the acceptable plants were used in the laboratory to obtain data on 12 additional traits. Mean values were calculated for each trait by families. The 10 families were ranked for each trait, with 1 the best and 10 the poorest expression of the trait. However, family rankings for only 7 of the more important traits are presented (table 1).

The 1953 evaluations showed that no single family was outstanding for all important traits. The frequency of high rank for the first six families listed did indicate that the remaining four families (135, 145, 155, and 4-8) were of questionable value as components in the variety.

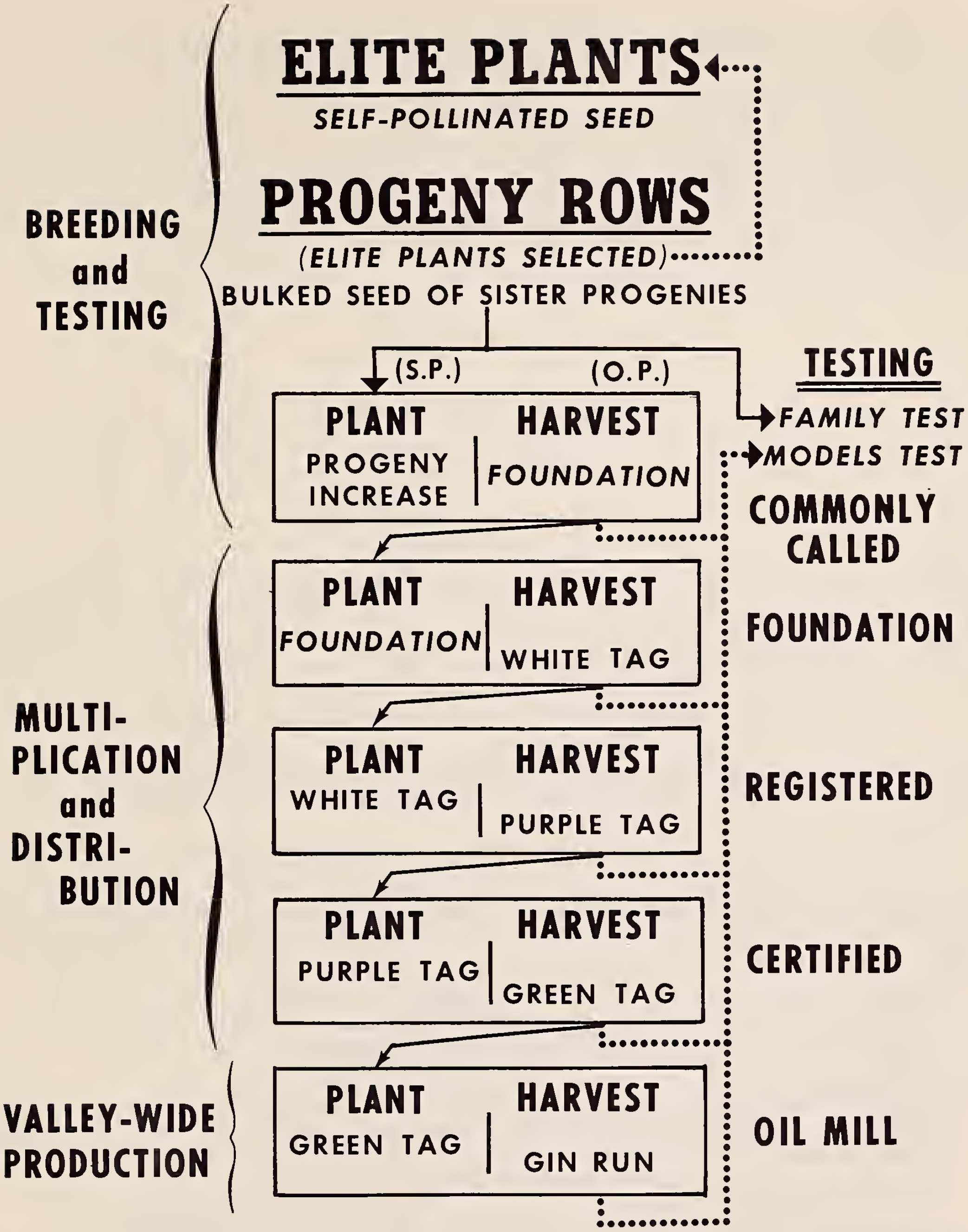

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Figure 1. Diagram of Breeding, Testing, and Seed Multiplication Program for Acala 4-42 Cotton in California.

Table 1. - Rank of 10 families of cotton for 7 important traits, 1953

Family number	Wilt tolerance	Stalk erectness	Crop maturity	Lint percentage	Fiber properties		
					Length	Strength	Fineness
77 ----	3	3	7	1	6	6	5
132 ---	4	1	2	5	8	3	2
176 ---	5	5	6	4	9	5	1
14 ----	8	8	1	7	2	7	7
94 ----	1	4	10	9	1	9	4
162 ---	6	7	4	2	5	1	3
135 ---	7	2	9	3	7	8	8
145 ---	9	9	8	10	9	4	6
155 ---	10	10	5	8	3	2	9
4-8 ---	2	6	3	6	10	10	10

From such breeding-nursery information, two types of decisions are made annually. They are:

1. The elite plants from the better progenies of each family are chosen. Self-pollinated seed from these plants is used to plant individual progeny rows in the breeding nursery the following year.

2. The better progenies within each family are determined. Open-pollinated seed from all acceptable plants in these progenies is bulked by families. These become family seed lots for use in testing the following year, while the self-pollinated seed from the same group of plants (excluding the elite plants) is bulked and grown in isolated increase blocks. Beginning in 1959, this procedure was improved by using some of the self-pollinated seed from the elite plants for an increase at Iguala, Mexico, during winter months; thus, sufficient seed of identical origin has been available for both testing and increase.

Occasionally, a section of the nursery is used to obtain other information. For example, the results of 6 years of selection pressure within three of the Acala 4-42 families were investigated in 1959. Reserve seed remnants from the 1952 selections which formed the respective family lines were grown in paired-row plots with 1958 selections of the same family. Mean values for 7 traits were obtained from 10 randomly chosen plants in each row (table 2). These data were gratifying in that (a) the 1958 selections show improvement over the 1952 selections for several traits, and (b) seed was available for use in the official seed release that came from isolated increases of the improved 1958 selections. This study was prompted by the advice from merchants and textile men that fiber length be increased in the variety.

Stage 2 - Family Testing

Performance trials conducted at several locations in the One-Variety district provide essential data for the breeders. One such experiment, known as the Family Test, was initiated in 1954. Replicated plots are grown on both wilt-infected and nonwilt soil each year.

The most critical decision in the varietal development is the choice of families to use in the official seed releases. From the Family-Test data, a valid comparison between (a) individual families, (b) the latest seed release (Foundation seed), and (c) experimental bulks is possible. Data obtained from 1954 through 1956 (table 3) illustrate the type of information from which the following decisions are made.

1. Families found to be inferior for yield or quality are eliminated.

2. Families showing valley-wide performance equal or superior to the latest seed release are chosen for use in the official release the next year.

3. The urgency of altering any specific traits in the variety to meet demands by the industry is taken into account before deciding the proportion of seed to use from each family increase block. Then, based on yield and quality data from both the Family Test and breeding nursery evaluation, the most appropriate seed composite is made up for official release.

Improvements in lint yield, wilt tolerance, and fiber strength were of paramount concern in the 1954 to 1956 period. The data (table 3) suggest that it was possible to make these important varietal improvements without loss of other desirable traits by using only families 77, 132, and 176 in the bulk for the official seed releases.

Stage 3 - Model Testing

The most advanced performance trial conducted in this varietal program is called the Model Test. The term "Model" indicates the crop year in which any specific Acala 4-42 seed release becomes available to all growers, after having been multiplied over a 3-year period (table 4 has example of seed-increase system).

Table 2. - Mean values for 7 traits of 1952 versus 1958 selections, when grown in 1959

Family number	Year	Wilt grade[1]	Stalk erectness[2]	Crop maturity[3]	Lint percentage	Fiber properties		
						Length, UHM[4]	Strength, T_1[5]	Fineness, A[6]
						Inches	G./grex[7]	$(mm)^{-1}$ [8]
77 ----	1952	0.64	2.2	2.8	38.2	1.10	2.05	495
	1958	.32	1.7	2.5	38.0	1.14	2.12	410
132 ---	1952	.60	1.5	2.7	38.4	1.09	2.09	440
	1958	.55	1.5	2.0	37.2	1.12	2.24	420
176 ---	1952	.51	2.2	2.9	38.0	1.09	2.08	430
	1958	.34	2.0	2.2	37.8	1.15	2.15	420

[1] Trace, 0.25; medium, .50; damaged, 1.00.

[2] Rigid, 1.0; leaning, 2.0; lodged, 3.0.

[3] Early, 1.0; medium 2.0; late, 3.0.

[4] Upper half mean.

[5] 1/8-inch gauge length.

[6] A is a measure of external fiber surface area.

[7] Below 1.90, weak; above 2.10, strong.

[8] Below 400, coarse; above 475, fine.

Table 3. - Family Test

Family number	Yield data for 3-year period					
	Lint, pounds per acre					
	Nonwilt soil			Wilt-infested soil		
	1954	1955	1956	1954	1955	1956
77	1,430	1,600	1,630	815	940	1,170
132	1,415	1,605	1,485	825	900	1,230
176	1,440	1,655	1,595	900	1,000	1,270
14	1,425	1,540	1,385	775	800	1,180
162	1,240	1,455	--	715	695	--
94	--	1,435	--	--	760	--
Check 1[1]	1,415	1,580	1,535	795	840	1,220
Check 2[2]	--	1,575	1,585	--	950	1,250
L.S.D. .05	104	90	130	78	78	60

Family number	Quality data in 1955			
	Fiber properties[3]			Yarn strength, 22 count[7]
	Length, UHM[4]	Strength, T_1[5]	Fineness, A[6]	
	Inches	G./grex[8]	$(mm)^{-1}$ [9]	Pounds
77	1.10	2.13	471	136
132	1.09	2.14	446	138
176	1.08	2.10	451	134
14	1.12	1.98	494	130
162	1.11	1.96	480	129
94	1.13	1.99	487	129
Check 1[1]	1.10	2.03	452	135
Check 2[2]	1.10	2.13	441	135

[1] 1955 Foundation seed release (a bulk composite of families 77, 132, 176, 14, 162, and 94).

[2] Experimental bulk composite (equal proportions of families 77, 132, and 176).

[3] Average of 2 locations.

[4] Upper half mean.

[5] 1/8-inch gauge length.

[6] A is a measure of external fiber surface area.

[7] Knoxville Min-Spin Laboratory data.

[8] Below 1.90, weak; above 2.10, strong.

[9] Below 400, coarse; above 475, fine.

Five successive models of planting seed are compared in valley-wide experiments each season. These entries represent the variety as grown the previous year, the current year, and that to reach the growers the 3 subsequent years. The latest seed release becomes a new entry each season while it is being multiplied as foundation stock, and the oldest model is dropped. Thus, we have a pattern like an assembly line, whereby each model remains in the chain for comparison for a 5-year period.

The information derived from the Model Test is important in several respects; the two most important being (a) to double check the decisions previously made on the basis of family testing and breeding-nursery evaluations and (b) to determine whether the latest seed release (foundation seed) performs satisfactorily. If it does not perform satisfactorily, it is still possible to withdraw this stock from the chain of multiplication and distribution. Growers, processors, and merchants also maintain a keen interest in the Model Test, since it gives them a preview of what varietal improvements may be expected before they reach valley-wide production.

From 1954 through 1962, the Model Test data were most gratifying to the breeder, in that the varietal improvements indicated from these data substantiated the breeder's estimates from earlier-stage evaluations. In some years, the latest seed release (Foundation) gave significant yield gains over previous models, but in most tests the gains between any two consecutive models were minor. More important were the slight, but consistent, varietal improvements shown for the planting seed models for 1954 through 1962 (fig. 2). The curves shown in figure 2 were derived from a summary of Model Test data after adjustments were made to eliminate seasonal and location effects. Thus, the cumulative gain for lint yield and fiber strength shown in the two curves depicts the genetic advances made through 9 generations of breeding in Acala 4-42, as nearly as this can be estimated from the Model Test results.

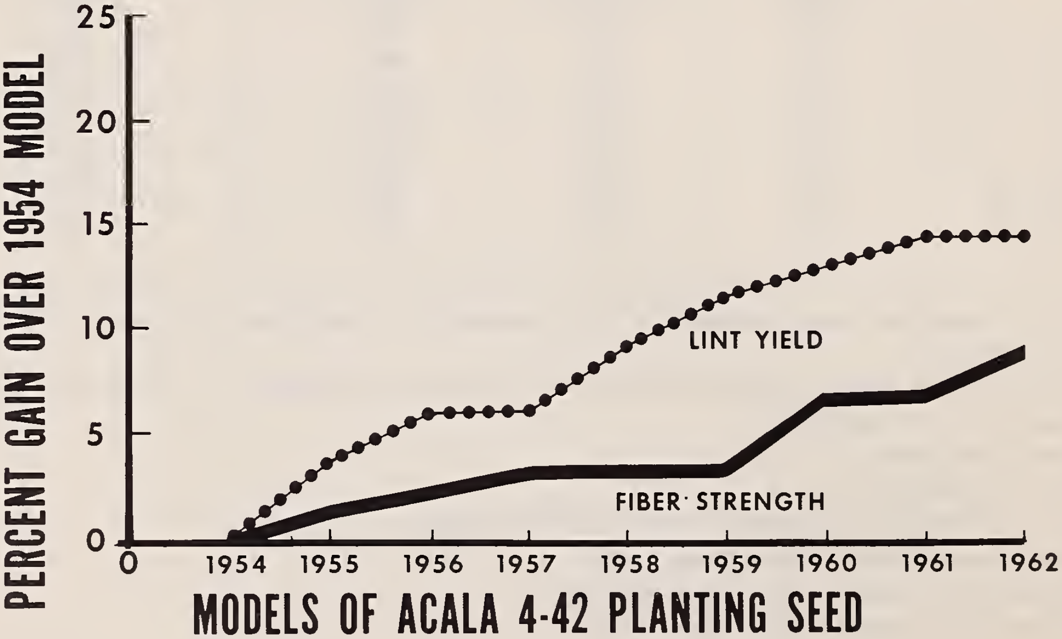

Figure 2. Cumulative Gain in Lint Yield and Fiber Strength for Acala 4-42 over Nine Generations of Seed Releases (Adjusted for Seasonal and Location Effects).

Table 4. - Family components included in 9 models of Acala 4-42

Foundation seed increase of	Family components included								Became model of planting seed for
	77	132	176	94	162	14	135	4-8	
1951---	x	x	x	x	x	x	x	x	1954
1952---	x	x	x	x	x	x	x	x	1955
1953---	x	x	x	x	x	x	x		1956
1954---	x	x	x	x	x	x	x		1957
1955---	x	x	x	x	x	x			1958
1956---	x	x	x	x	x	x			1959
1957---	x	x	x						1960
1958---	x	x	x						1961
1959---	x	x	x	(plus 6-1-5, a newly developed family)					1962

Example:

1951 Foundation - 250 acres

↓

1952 White Tag - 3,500 acres

↓

1953 Purple Tag - 60,000 acres

↓

1954 Green Tag - Valley-wide production*

*All seed go to oil mills for crushing.

DISCUSSION

The development of the family components making up the commercial seed releases of Acala 4-42 is essentially a pure line pedigreed method in that self-pollinated seed from individual plants form the basic unit. Deviations from conventional pure line breeding occur at the stages where seed of sister progenies is bulked to form family lots for increase and where family lots are bulked to form the official seed release each year.

Looking back on what has been done within the Acala 4-42 variety in order to make genetic advances, the question naturally arises as to how long such improvements can continue. Evidently, genetic variability was being reduced in this program because of selective pressure within the family components and through the occasional elimination of a family in the commercial seed releases. Two plant selections of 1946 gave rise to all the families used in planting seed models from 1954 through 1962. Even if it is assumed that these two selections were equivalent to an F_2 in heterozygosity, it would mean that 12 generations of inbreeding were involved in the 1958 seed release that became the 1961 model of planting seed.

Anticipating the time when yield and quality gains within the variety will reach a plateau, the breeder has initiated slight modifications in the breeding methods.

First, to avoid retrogression in the variety, a shift was made in 1960 whereby the unit of selection became the progeny row rather than the individual plant for the three major family components.

Second, certain new families were composited with the Acala 4-42 families for testing. This phase of the modification is to evaluate the possibility of increasing both the genetic diversity and the agronomic gains without making a drastic change in the commercial variety (table 4).

Third, many new and promising families are continually being developed in the breeding nursery. These families are sib lines of new Acala strains having parents so diverse in genotype that incorporation within the Acala 4-42 variety does not appear to be a logical approach. Since 1960, such families have been used to form experimental strains for use in a valley-wide strain test. Actually, these experimental strains are competing annually with the latest seed release of Acala 4-42. The results from the replicated valley experiments largely determine which entry is to become the following year's official seed release in this One-Variety program.

Two theories that relate to breeding methods for self-pollinated crops might be expected to play a role in this One-Variety cotton program. They are:

1. Stephens' (9), Simpson's (8), and Duncan's (2) theory was that yield gains result from partially hybridized cotton.

2. Allard's (1) and Gustafsson's (3) theory was that components in a mixed population of genotypes may complement each other in the environment to such an extent that the mixture is superior to the average of the components.

The amount of natural crossing was estimated by the use of the glandless boll marker strain (5). From widely scattered valley sites the indications were that cross-pollination was below 5 percent in most fields, with over 20 percent from only one field site. In areas where the official seed releases were multiplied, natural crossing estimates were all below 10 percent. Under such conditions, little genetic exchange between the family components of Acala 4-42 could be expected. This was supported by data from a study (6) involving the 1960 model of planting seed, derived from different multiplication steps of increase, which showed that yield and quality were not influenced by extra years of multiplication.

The breeder has not been encouraged to suggest means of increasing natural crossing in the seed multiplication fields. An experimental seed composite of more diverse parentage than Acala 4-42 was exposed for intercrossing at the site with the highest natural crossing (30 percent). After two generations of exposure to hybridization, this composite gave no added yield over its best family component; the same unexposed composite gave yield and quality equivalent to the best features from both parents (11).

Since natural crossing is practically nil, the second theory appears to be more operative than the first theory in this breeding and seed-increase program.

Many factors may determine the productivity of family bulks. Some data have indicated that favorable genotypic interactions exist. Family differences, which may be one contributing factor to these results, were identified in the growth-fruiting pattern. In respect to fiber quality, the system of bulking families proved satisfactory since, by maintaining family lines separately, the breeder has more control of the genetic diversity coming from breeding nursery developments. The present system has also allowed greater flexibility in making timely alterations in the varietal releases. Each season the breeder has (a) appraised the demands from farm and factory; (b) evaluated the Models of seed on the assembly line of increase; (c) determined the relative value of each potential family; (d) gained some indication of the improvements forthcoming from breeding-nursery progenies; and, then, arrived at the decision as to the most appropriate components for use in the official release.

Finally, some aspects of breeding defy description, since they involve a combination of art and science. For many attributes of yield and production efficiency, the breeder's practical experience with the cotton plant remain the decisive factor. Modern instruments and techniques have gradually made it possible for the breeder to be more and more objective in his evaluations of quality traits. Further refinement of techniques could lead to more rapid genetic advances.

Given an obligation to release seed, no breeder can wait for research solutions to the complex problems of genetics and breeding methodology. He must take the material and information on hand and move ahead. Promising innovations are currently being investigated, but the breeder cannot afford to venture forth with new methods until their worth has been proved. Present methods are not all that could be desired, but they have been successful.

SUMMARY

Acala 4-42 has been the variety grown in the San Joaquin Valley One-Variety cotton district since 1949.

Maintenance and improvement of the variety have been accomplished by a modified pure line breeding method. This system allows the breeder more opportunity to alter the genotypic constitution of the variety to meet changing demands from the producer, the merchant, and the processor.

Evaluations and decisions are made annually in three stages of varietal development:

1. In the breeding nursery, the elite plants and the better progenies of each family line are chosen.
2. In the Family Test, each family line, several experimental bulks, and the latest bulk used as the seed releases are compared on both wilt-infected and nonwilt soil. Data from this stage of testing are used to determine the families and proportion of each to include in the next official release. A reduction from 10 to 3 families occurred between 1950 and 1960 as improvements were made in lint yield, wilt tolerance, and fiber strength.
3. In the Model Test, the planting seed stock of 5 successive years are compared in valley-wide experiments. The information provides a double check on former decisions and is important because the latest seed release can be withdrawn from the chain of multiplication if it does not perform satisfactorily. The Model Test data from 1954 through 1962 show that gains were made for yield and fiber strength.

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